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AN EVALUATION OF THE 225W ELECTRON BEAM MACHINE.(U)

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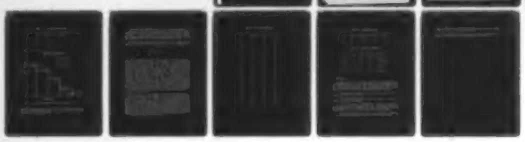

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AN EVALUATION OF THE 225W ELECTRON BEAM MACHINE

HARRY DIAMOND LABORATORIES
ADELPHI, MARYLAND

DECEMBER 1976

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Diagnostic experiments have been conducted by the Harry Diamond Laboratories to determine the beam characteristics of the Physics International (PI) 225W Electron Beam Machine. The purpose of these experiments was to provide reproducibility, uniformity, and depth-dose information for material experiments being conducted by personnel from Los Alamos Scientific Laboratory. The 225W utilizes magnetic-beam transport; hence many stable fluence levels and beam sizes were available. However, only the 45 cal/cm^2, 6.5-cm^2 area

level was studied. At this level, the shot-to-shot reproducibility had a standard deviation which was 10 to 12 percent of the mean. It was also found that the beam had an annular pattern, sometimes varying as much as 60 percent from the mean fluence. The diode diagnostics, as well as a PI Faraday cup, were used to generate an electron energy spectrum having an average electron energy of 247 keV. This spectrum was used, in turn, to predict the depth-dose profile in carbon.

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1. INTRODUCTION

During the week of 6 to 10 January 1976, Harry Diamond Laboratories participated in a series of experiments using the Physics International (PI) 225W Electron Beam Machine. The primary purpose of these experiments was to determine the response of materials developed by S. R. Skaggs of Los Alamos Scientific Laboratory (LASL) to a pulsed electron beam. However, it was necessary to determine several beam characteristics such as reproducibility, uniformity, and energy spectrum to evaluate those tests. Only the results of the beam studies will be presented here because Dr. Skaggs has presented his experimental results separately.*

2. PROCEDURE

During this study, the 225W machine, an oil-water line, was operated with a 0.7-MV pulse charge, and the distance between the stainless steel cathode and the 1/4-mil (6.4 μm) aluminized mylar anode was held constant at 5 mm. Since the 225W uses a magnetic transport system, it is a rather simple task to vary the fluence and the beam size by varying the sample or calorimeter position in the magnetic lens. Therefore, during this sequence, investigating various fluence levels seemed unnecessary, and consequently, the position in the magnetic lens was held constant (4:1 compression) except for the depth-dose shots.

Like most other high-fluence machines, the 225W operates in a manner that precludes measurement of the electron fluence or total energy on each data shot. Therefore, it was assumed that the fluence on a data shot was the mean fluence of the calorimeter shots that were interspersed with the data shots in the test sequence. However, knowledge of beam reproducibility, possibly the most important characteristic of the beam, is essential to evaluate the dependability of these statistics.

To estimate the reproducibility, the total energy delivered to a calorimeter for a series of pulses was obtained from the total stopping and the multiprobe calorimeters. For the multiprobe calorimeter, the total energy was taken to be the sum of all the individual probe energies.

In some cases, normal machine diagnostics (pulse charge, diode voltage, current loop, and corrected voltage) can be used to make a

**S. R. Skaggs, Electron Beam Test on Some Borides (U), Los Alamos Scientific Laboratory Report LA-5557, to be published (CONFIDENTIAL FORMERLY RESTRICTED DATA).*

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refined estimate of the fluence on a data shot. The total energy in the diode is calculated from the machine diagnostics and then compared to the total energy in the calorimeter during the series of tests for reproducibility. If the calorimeter position is held constant and magnetic transport is used, the percentage of energy lost between the diode and the sample would be relatively constant. This permits estimation of fluence on data shots.

In an ideal situation, the fluence should be completely uniform over the exposure area. However, perfect uniformity never exists for any electron beam, so the experimenter needs to know the degree of uniformity. To measure the uniformity of the beam, a multiprobe calorimeter (an array of small calorimeter probes) is often employed. Two square multiprobe arrays consisting of 25 probes each were used. In one array, the probes were 0.5×0.5 cm and, in the other, the probes were 1×1 cm.

All the calorimeters used in these tests were made from ATJ graphite with iron-constantan thermocouples attached to measure the temperature change. The thermocouple response was then measured by a Vidar Scanning Digital Voltmeter. In most cases, it was assumed that the peak voltage reading from the Vidar output was equal to voltage extrapolated from the cooling curve at zero time.

To predict the depth-dose profile and ultimately the material response, it was necessary to calculate the electron energy spectra. During this study, three types of measurements were made to ascertain the spectra. First, the diode current and voltage were measured on each shot as a part of the normal machine diagnostics and then were used to calculate an energy spectrum. Next, the current was measured at the target area with a Faraday cup. This current is used to determine any change of spectrum or loss of beam current in transporting the beam. Although the output of the Faraday cup tends to "hang up" instead of decreasing to zero when the voltage decreases to zero, the Faraday cup was used for several shots and the results, combined with the diode voltage, were used to calculate the energy spectra.

Since the Faraday cup, like fluence calorimetry, could not be used on data shots, the diode energy spectrum and depth-dose profile were compared with the Faraday cup spectra and profile to justify the use of the diode spectra on data shots.

Since it was inconvenient to measure the energy spectrum directly, experimental determination of the depth-dose profile in carbon was attempted using a carbon depth-dose calorimeter. These experimental results were then compared with the calculated depth-dose profiles for carbon using both the diode and Faraday cup spectra to verify the accuracy of the computed spectra.

3. RESULTS

The multiprobe calorimeters were used for both uniformity and reproducibility measurements. The larger probe array was found to be more suitable for the reproducibility study. Although three of the peripheral probes were inoperative, most of the beam was concentrated in the central 3 × 3 cm area, so that very little information was lost. Table I is a summary of the data from this calorimeter series. To indicate the reproducibility of the beam, the total recorded energy of each shot is listed along with the mean and standard deviation of the total energy.* The total energy measured by the active probes was calculated from PI's Calorimeter Reduction Program.

TABLE I. LARGE MULTIPROBE CALORIMETER RESULTS

Shot No.	Total energy (kJ)	Mean fluence (cal/cm^2)	$\Delta E+$ (%)	$\Delta E-$ (%)
147	1.35	33.8	45	-70
149	1.35	34.7	30	-62
150	1.34	31.8	27	-37
151	1.27	32.0	34	-71
156	1.64	41.6	42	-57
166	1.44	37.3	34	-60
	μ = 1.40			
	σ = ±9.3%			

To illustrate the degree of uniformity, the mean fluence of the nine center probes (3 × 3 cm area) is given, along with the percentage difference from the mean of both the probe with the highest fluence ($\Delta E+$) and the probe with the lowest fluence ($\Delta E-$). Several fluence maps, chosen randomly, are exhibited in figure 1.

The small multiprobe calorimeter was similar to the large multiprobe calorimeter in construction and monitoring method. However, a carbon

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$$^*\mu = \sum_{i=1}^{n} \frac{X_i}{n}$$

$$\sigma^2 = \sum_{i=1}^{n} \frac{\left(X_i - \mu\right)^2}{n - 1}$$

0.5	X	10	X	1.4
4.9	40	35	29	2.2
4.6	34	28	39	X
1.2	22	40	20	1.4
0.1	1.2	6.3	1.0	0.1

SHOT NO. 150

UNITS: cal/cm^2

0.1	X	4.0	X	0.5
2.0	38	43	25	0.9
3.5	43	34	35	X
0.7	21	40	9.4	0.4
0.1	0.8	1.2	0.3	0.5

SHOT NO. 151

UNITS: cal/cm^2

Figure 1. Uniformity map: large multiprobe calorimeter (x = inoperative probe).

mask with a 2.86-cm diam hole was placed in front of the calorimeter to duplicate the sample testing configuration.

The same statistical analyses were used to characterize the results from both calorimeters. The results from the smaller probe calorimeter are displayed in table II. However, for the small multiprobe calorimeter the four corner probes were not used to determine the mean fluence, because they were partially shadowed by the graphite mask. Figure 2 displays fluence maps for two shots where the small calorimeter

TABLE II. SMALL MULTIPROBE CALORIMETER RESULTS

Shot No.	Total energy (kJ)	Mean fluence (cal/cm^2)	$\Delta E+$ (%)	$\Delta E-$ (%)
158	1.06	51.5	28	-52
163	1.24	58.8	22	-39
170	0.94	44.3	33	-46
173	0.88	41.8	63	-62
182	1.00	46.8	32	-47
196	1.01	45.8	53	-47
	μ = 1.02			
	σ = ±11.8%			

4.0	X	43	X	20
35	65	58	47	61
58	66	46	44	58
25	66	59	55	40
40	46	63	44	12

SHOT NO. 158
UNITS : cal/cm^2

22	X	58	X	14
62	44	36	45	55
56	34	25	49	53
47	48	40	51	39
16	50	52	45	26

SHOT NO. 182
UNITS : cal/cm^2

Figure 2. Uniformity map: small multiprobe calorimeter (x = inoperative probe).

was used. Since the fluence maps indicate fluctuation in the uniformity of the beam, the percentage differences from the mean for several probes for a series of shots were compared to establish a consistent pattern from shot to shot. The results are displayed in figure 3.

Two probes in the smaller calorimeter were inoperative during these shots so the total energy could not be measured. However, if it is assumed that the inoperative probes had the mean probe fluence, then the total energy would be approximately 10 percent higher than the total energy as shown in table II. Table III gives these estimated total energy values. To avoid the problem of inoperative probes in measuring the total energy, a single-piece, total-stopping calorimeter, constructed by PI personnel, was employed. Unfortunately, only one valid data shot was obtained (total energy = 1.82 kJ). For comparison, the integrated power at the diode was calculated for several pulses. Those data are shown in table IV.

The depth-dose calorimeter, used to measure the profile, consisted of a stack of 5-mil (0.013-cm) graphite foils monitored by thermocouples and was located 34.3 cm behind the mirror throat because several of the front foils shattered if the calorimeter was placed in the sample position. Unlike the previous calorimeter data, the cooling curves were plotted from the Vidar output and the thermocouple potential difference was extrapolated and read at zero time.

The spectrum for the depth-dose calorimeter shot was calculated by using current and corrected voltage data, and the resulting spectrum was

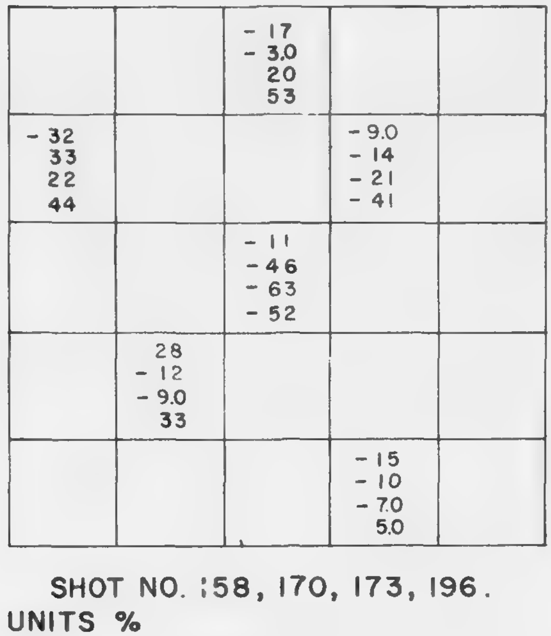

Figure 3. Consistency map: small multiprobe calorimeter.

TABLE III. TOTAL ENERGY CORRECTION

Shot No.	Total energy reading (kJ)	Estimated total energy (kJ)
158	1.06	1.17
163	1.24	1.36
170	0.94	1.03
173	0.88	0.97
182	1.00	1.10
196	1.01	1.11

then used in the ZEBRA[1] code to calculate the profiles. Figure 4 shows the experimental results and the calculated depth-dose profiles for both

[1] *Lawrence D. Buxton, The Electron Transport Code ZEBRA 1, Harry Diamond Laboratories TR-1536 (June 1971).*

TABLE IV. TOTAL ENERGY CALORIMETRY

Shot No.	Integrated power (kJ)	Total calorimeter energy (kJ)
167	1.91	-
190	-	1.82
193	2.17	-
195	2.11	-

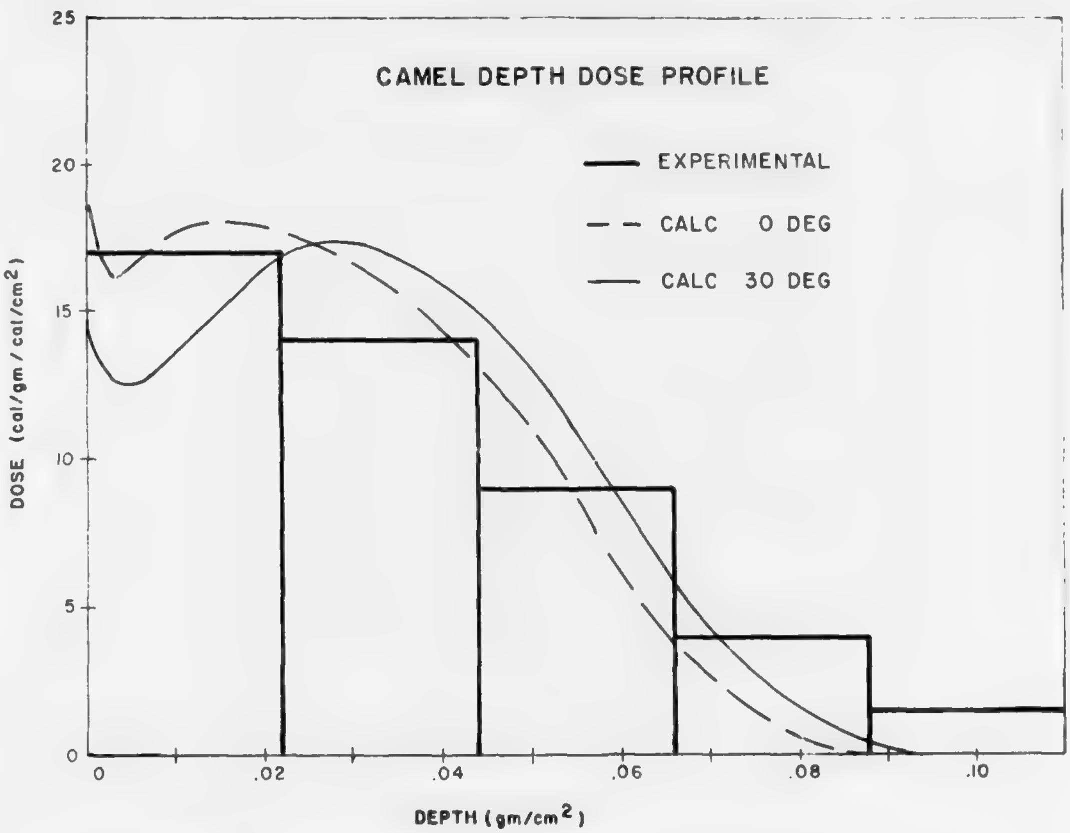

Figure 4. Depth-dose profile in carbon for shot No. 167.

0- and 30-deg angles of incidence. The data in this figure are for shot No. 167, where the integrated power at the diode was 1.907 kJ, and the average electron energy was 247 keV.

To estimate the reproducibility of the spectrum parameters, the spectra for 26 shots were calculated by using a sonic digitizer and a minicomputer. The resulting calculations are accurate to ±5 percent. In table V, the integrated power, the average electron energy, and the total number of electrons are displayed for each shot, and the mean and the standard deviation for each of these parameters are given.

For shots No. 193 and No. 195, the collector of the Faraday cup was used as a calorimeter, and the energy delivered to it was computed from

$$\int_0^{t_o} V(t)I(t)dt ,$$

where t_o is the beam-shine time. This integral was evaluated for the Faraday cup current and diode current monitor, I_1. Since the Faraday cup current tends to "hang up" late in the pulse instead of decreasing to zero with the voltage (and with I_1), it was extrapolated from the inflection point to zero at the time when the voltage drops to zero. The energy calculations from the Faraday cup current, the extrapolated current, the diode current, and the calorimeter results are shown in table VI. From the table it is obvious that the extrapolation of the current to zero makes very little difference. The doses recorded by the collector cup calorimeter for both shots are much lower than the calculated doses. Discussion of this discrepancy with PI personnel initiated a recheck of the calibration factors of all the monitors, but no satisfactory explanation was found. Some calorimeter shots suggested that the Faraday cup may have received a sufficient dose to spall some material off the front surface, thereby reducing the energy registered by the calorimeter. Although the evidence is not thoroughly convincing, it is possible that about 30 percent of the observed difference could be accounted for in this way.

It is desirable to know the number of pulses that can be planned for one day. Table VII gives the number of pulses per day and the time of the first and last shot. Also listed in the table are the prefires, shorts, and low voltage shots. These malfunctions were determined on the basis of normal machine diagnostics, i.e., abnormal current and voltage traces. On 9 January 1976, there were four low-voltage shots and one short. On that day, the LASL samples being tested were fabrics. It was postulated that the fabric debris remaining in the diode area after cleaning was the cause for some of the machine malfunctions. During the week of 6 to 10 January 1976, the 225W was operated with two technicians and one physicist, who were able to "turn the machine around" in 30 to 40 min depending on the nature of the shot.

TABLE V. SPECTRUM PARAMETERS

Shot No.	Integrated power (kJ)	<E> (keV)	No. of electrons ($\times 10^{16}$)
157	2.11	279	4.64
158	2.21	273	5.06
161	2.06	284	4.50
162	2.42	287	5.24
163	2.31	306	4.71
164	2.39	286	5.20
166	1.96	256	4.78
167	1.86	243	4.78
170	1.86	261	4.43
171	2.17	295	4.58
172	1.95	244	4.98
175	1.97	234	5.25
178	2.27	268	5.28
180	2.52	223	7.07
181	2.00	279	4.46
182	2.15	264	5.09
183	2.07	271	4.77
184	1.72	246	4.36
186	2.07	270	4.77
188	2.10	255	5.14
190	1.76	262	4.18
192	2.38	255	5.81
193	2.30	275	5.22
196	2.22	318	4.35
197	2.42	306	4.93
199	1.98	240	5.13
	$\mu = 2.12$	$\mu = 268$	$\mu = 4.95$
	$\sigma = \pm 11\%$	$\sigma = \pm 8.7\%$	$\sigma = \pm 11.6\%$

TABLE VI. INTEGRATED POWER

Shot No.	Faraday cup (kJ)	Extrapolated Faraday cup (kJ)	Diode current (kJ)	Calorimeter (kJ)
193	2.32	2.29	2.17	0.91
195	1.89	1.85	2.11	0.91

TABLE VII. CAMEL PULSE FREQUENCY

Date	No. of shots	First shot (time)	Last shot (time)	Malfunctions	
				No.	Type
6 Jan 1976	9	1045	~1700	1	Prefire
7 Jan 1976	11	0900	1650	1	No magnetic field (human error)
8 Jan 1976	12	0905	1630	2	Low voltage
9 Jan 1976	14	0950	1745	4 1	Low voltage Short
10 Jan 1976	9	0900	1650	1 1	Low voltage Prefire

4. CONCLUSIONS

In summary, the PI 225W Electron Beam Machine was operated with a 0.7-MV pulse charge and a 5-mm anode-cathode gap producing electrons with average energy of 250 keV. The calorimeters and samples were in the 4:1 compression position of the magnetic-transport system. Under these conditions, the following characteristics were obtained:

a. The standard deviation of the shot-to-shot variation in the total energy was 10 to 12 percent.

b. With the magnetic-transport system, there was a wide range of fluences and beam sizes available.

c. At the fluence level investigated (~45 cal/cm^2, 6.5-cm^2 area), the fluence pattern of the beam was annular. The hottest probe fluence was generally 20 to 60 percent higher than the mean fluence, and the coolest probe was 40 to 60 percent lower than the mean fluence.

d. The depth-dose profile for carbon was adequately predicted by using both the diode diagnostics and the Faraday cup current. The

Faraday current (at the target position) closely matched the diode current for about 2/3 of the pulse's length.

e. Ten acceptable shots per day could be expected depending on the experiment (a minimum time is approximately 30 to 40 min).